

Dihadron Production at LHC: BFKL Predictions for Cross Sections and Azimuthal Correlations

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Abstract.

A study of the inclusive production of a pair of hadrons (a “dihadron” system), having high transverse momenta and separated by a large interval of rapidity, is presented. This process has much in common with the widely discussed Mueller–Navelet jet production and can be also used to access the BFKL dynamics at proton colliders. Large contributions enhanced by logarithms of energy can be resummed in perturbation theory within the BFKL formalism in the next-to-leading logarithmic accuracy. The experimental study of dihadron production would provide with an additional clear channel to test the BFKL dynamics. The first theoretical predictions for cross sections and azimuthal angle correlations of the two hadrons produced with LHC kinematics are presented.

INTRODUCTION

The amplex of data being produced at the Large Hadron Collider (LHC) offers us a faultless chance to study the dynamics of strong interactions in the high-energy limit. In this kinematical regime, the Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach [1] represents the most effective tool to perform the resummation to all orders of the leading (LLA) and the next-to-leading terms (NLA) of the QCD perturbative series which are heightened by powers of large energy logarithms. The inclusive production of two jets with high transverse momenta and well separated in rapidity, known as Mueller–Navelet reaction [2], has been one of the most studied processes in the last years. For this reaction, the BFKL resummation with NLA accuracy relies on the combination of two ingredients: the NLA Green’s function of the BFKL equation [3, 4] and the NLA jet vertices [5–9]. In [10–21] NLA BFKL predictions of cross sections and azimuthal angle correlations for the Mueller–Navelet jet process, observables earlier proposed in [22–25], were given, showing a very good agreement with experimental data at the LHC [26]. In order to further and deeply probe the dynamical mechanisms behind partonic interactions in the Regge limit, $s \gg |t|$, some other observables, sensitive to the BFKL dynamics, should be considered in the context of the LHC physics program. An interesting option, the detection of three and four jets, well separated in rapidity from each other, was recently suggested in [27, 28] and investigated in [29–32]. In this paper a novel possibility, *i.e.* the inclusive production of two charged light hadrons: π^\pm , K^\pm , p , \bar{p} featuring high transverse momenta and separated by a large rapidity interval, together with an undetected gluon radiation emission is proposed (see Figure 1). For this process, similarly to the Mueller–Navelet reaction, the BFKL resummation in the NLA is viable, since NLA expression for the vertex describing the production of an identified hadron, was obtained in [33]. On one side, hadrons can be detected at the LHC at much smaller values of the transverse momentum than jets, allowing us to explore an additional kinematic range, supplementary to the one studied with Mueller–Navelet jets. On the other side, this process makes it possible to constrain not only the parton densities

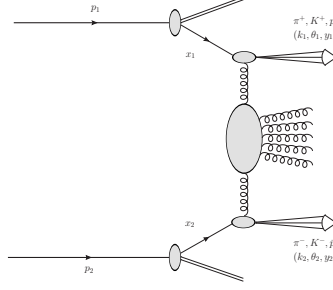


Figure 1. Inclusive dihadron production process in multi-Regge kinematics.

(PDFs) for the initial proton, but also the parton fragmentation functions (FFs) describing the detected hadron in the final state. It is known that the inclusion of NLA terms makes a very large effect on the theory predictions for the Mueller–Navelet jet cross sections and the jet azimuthal angle distributions. Similar features are expected also for our case of inclusive dihadron production. This results in a large dependence of predictions on the choice of the renormalization scale μ_R and the factorization scale μ_F . Here we will take $\mu_R = \mu_F$ and adopt the Brodsky-Lepage-Mackenzie (BLM) scheme [34] for the renormalization scale setting as derived in its “exact” version in [35].

DIHADRON PRODUCTION AT THE LHC

The process under investigation is the hadroproduction of a pair of identified hadrons in proton-proton collisions

$$p(p_1) + p(p_2) \rightarrow h(k_1, y_1, \phi_1) + h(k_2, y_2, \phi_2) + X, \quad (1)$$

where the two hadrons are characterized by high transverse momenta, $\vec{k}_1^2 \sim \vec{k}_2^2 \gg \Lambda_{\text{QCD}}^2$ and large separation in rapidity $Y = y_1 - y_2$, with p_1 and p_2 taken as Sudakov vectors. The differential cross section of the process can be presented as

$$\frac{d\sigma}{dy_1 dy_2 d|\vec{k}_1| d|\vec{k}_2| d\phi_1 d\phi_2} = \frac{1}{(2\pi)^2} \left[C_0 + \sum_{n=1}^{\infty} 2 \cos(n\phi) C_n \right], \quad (2)$$

where $\phi = \phi_1 - \phi_2 - \pi$, with $\phi_{1,2}$ the two hadrons’ azimuthal angles, while C_0 gives the total cross section and the other coefficients C_n determine the azimuthal angle distribution of the two hadrons. In order to match the kinematic cuts used by the CMS collaboration, we consider the *integrated coefficients* given by

$$C_n = \int_{y_{1,\min}}^{y_{1,\max}} dy_1 \int_{y_{2,\min}}^{y_{2,\max}} dy_2 \int_{k_{1,\min}}^{\infty} dk_1 \int_{k_{2,\min}}^{\infty} dk_2 \delta(y_1 - y_2 - Y) C_n(y_1, y_1, k_1, k_2) \quad (3)$$

and their ratios $R_{nm} \equiv C_n/C_m$. For the integrations over rapidities and transverse momenta we use the limits, $y_{1,\min} = -y_{2,\max} = -2.4$, $y_{1,\max} = -y_{2,\min} = 2.4$, $k_{1,\min} = k_{2,\min} = 5$ GeV, which are realistic values for the identified hadron detection at LHC. We use the PDF set MSTW 2008 NLO [36] with two different NLO parameterizations for hadron FFs: AKK [37] and HKNS [38]. Pursuing the goal to stress the potential relevance of the process we are proposing, rather than to give a high-precision prediction, we present our first results neglecting the NLA parts of hadron vertices and planning their inclusion as the main goal of a later, more technical publication. In Figure 2 the dependence on the final state rapidity interval Y , of the ϕ -averaged cross section C_0 and of the ratios R_{10} , R_{20} , and R_{30} at the center-of-mass energy $\sqrt{s} = 13$ TeV is shown. Our predictions with the AKK FFs give bigger cross sections, whereas the difference between AKK and HKNS in the azimuthal correlation momenta is small, since the FFs uncertainties are largely canceled out when we take the ratios R_{n0} . The general features of our predictions are rather similar to the respective ones of the Mueller–Navelet jet process. Although the BFKL resummation predicts a growth with energy of the partonic cross section, the convolution of the latter with proton PDFs leads to a decrease with Y of C_0 . The decreasing behavior with Y of the R_{n0} azimuthal ratios is due to the increasing amount of undetected parton radiation X (see Equation (1)) in the final state allowed by the growth of the partonic subprocess energy. We present our NLA BLM predictions together with the results we obtained in LLA, using both BLM and natural scale setting ($\mu_R^2 = \mu_F^2 = |\vec{k}_1||\vec{k}_2|$, always smaller than the BLM one). Plots of Figure 2 show that LLA results at BLM scales lie closer to the NLA BLM ones than LLA results at natural scales.

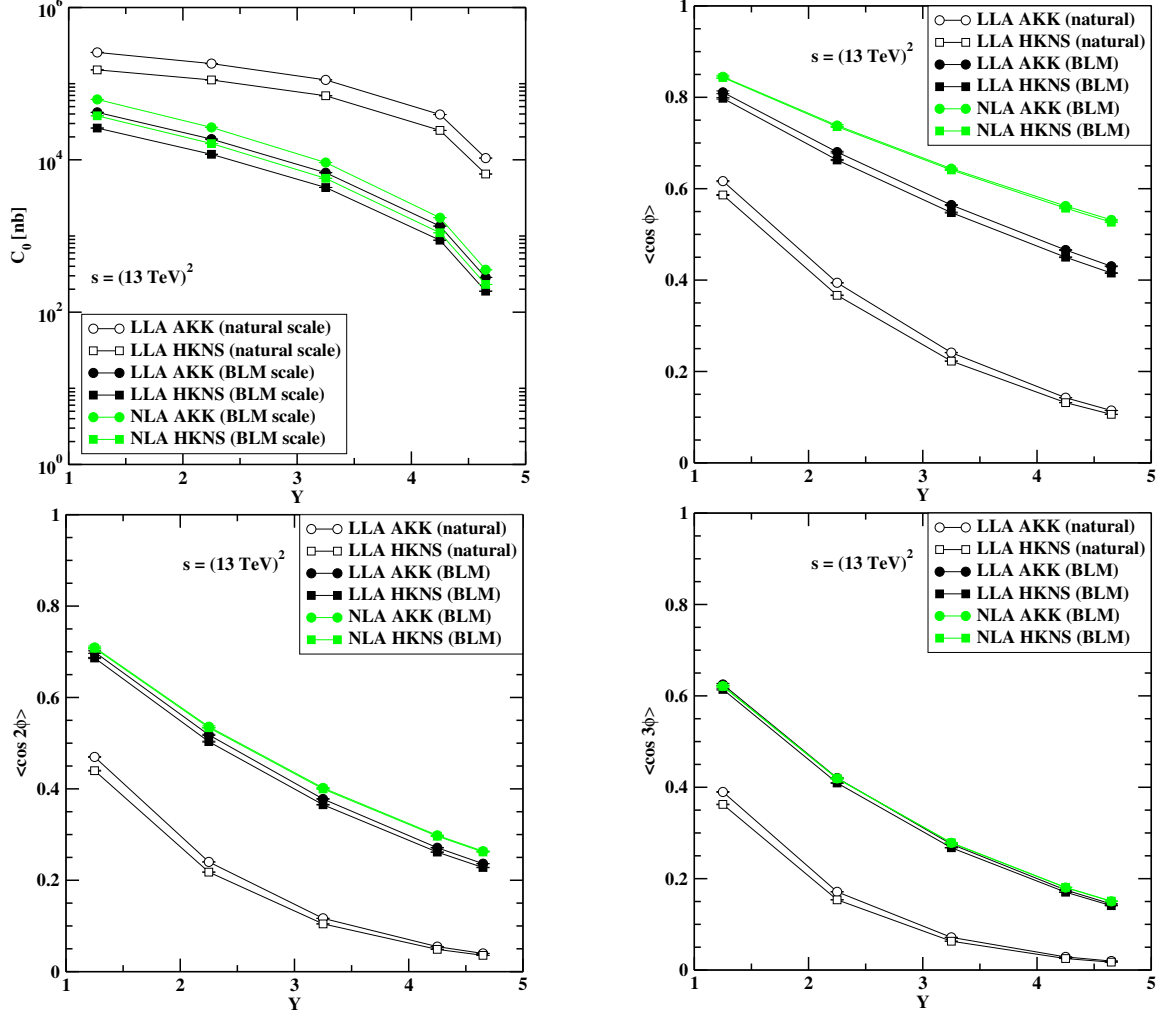


Figure 2. Y dependence of cross section, $R_{10} \equiv \langle \cos \phi \rangle$, $R_{20} \equiv \langle \cos 2\phi \rangle$, and $R_{30} \equiv \langle \cos 3\phi \rangle$ for dihadron production at $\sqrt{s} = 13$ TeV. See Ref. [39] for predictions of C_0 and R_{10} given at larger values of Y , similar to the ones used in the CMS Mueller–Navelet jets analysis.

CONCLUSIONS AND OUTLOOK

In this paper we investigated the dihadron production process at the LHC at the center-of-mass energy of 13 TeV, giving the first theoretical predictions for cross sections and azimuthal angle correlations in the LLA and partial NLA BFKL approach. We implemented the exact version of the BLM optimization procedure in order to make completely vanish the β_0 -dependence in our observables and minimize the size of the NLA corrections. We found that our NLA BLM predictions are close to the LLA BLM ones, while the LLA calculations at natural scales overestimate the total cross section C_0 and predict a stronger decorrelation for the azimuthal ratios R_{n0} . The good agreement between LLA and NLA at BLM scales is a direct consequence of the small size of the higher-order corrections, representing so a clear signal of the reliability of the BLM method. However, more accurate analyses are still needed: full NLA calculations including next-to-leading order hadron vertices, together with the study of larger rapidity intervals in the final state and considering the effect of a different choice for the factorization scale μ_F with respect to the renormalization scale μ_R , are underway [40]. In view of all these considerations, we encourage experimental collaborations to include the study of the dihadron production in the program of future analyses at the LHC, making use of a new suitable channel to improve our knowledge about the dynamics of strong interactions in the Regge limit.

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